such a procedure is certain to give more satisfactory results. They were then plotted as a curve 400 millimeters long.

Twenty of these harmonics showed amplitudes large enough to indicate possible reality. This fact alone indicated clearly that the correlation found was due to many terms. However, a synthesis was made from the eight largest terms. It was no better than that made by extrapolation and, therefore, no predictions are tried from it. Of course all the harmonics could be used for a synthesis which would represent *past* data more accurately than was done.

Seventy-five years' data were used. It may be possible to secure data taken before 1850 sufficiently accurate to use. Eleven years of such data would make it possible to extrapolate from averages of two datum values. If not, the 43-year period will be completed twice by the end of 1935 and any accuracy which may be found for predictions now should be materially increased after that date.

It is quite probable that for any one of three causes the length of the 43-year term may shift as time goes on. These causes have been thoroughly discussed in the previous papers and need only be mentioned here.

In conclusion, a period approximately 43 years, with harmonics, exists in the rainfall data of the British Isles. It may be complex, it may be constant, and it may be variable; time alone can tell which of these is true. Whether predictions made by it at present, or even at some future time, can have economic value is uncertain. However, the chances are sufficient to warrant the attempt, if it be sufficiently emphasized that the predictions are for test purposes only.

About half of the computations for this paper were made under a grant from the Research Committee of the Graduate School of the University of Kansas. I wish also to express my thanks to Professor Miller for the analysis made by him. Without that aid, part of the contemplated work would have remained incomplete on account of lack of time.

TABLE 1.—*Test predictions for British Isles rainfall through 43-year extrapolation*

[A indicates first half of the year, B the second half. Wet, normal, and dry as defined in body of the paper]

	Data A	Data B		Data A	Data B
1925—A	Wet	Wet.	1931—A	Dry	Dry.
B	do	Do.	B	Normal	Normal.
1926—A	Normal	Dry.	1932—A	Dry	Do.
B	do	Normal.	B	do	Do.
1927—A	do	Do.	1933—A	Normal	Dry.
B	Dry	Wet.	B	do	Normal.
1928—A	Normal	Dry.	1934—A	Dry	Do.
B	Dry	Do.	B	Wet	Wet.
1929—A	Wet	Wet.	1935—A	Dry	Dry.
B	Normal	Normal.	B	Normal	Normal.
1930—A	Dry	Dry.	1936—A	Dry	Dry.
B	do	Do.	B	Normal	Do.

ADDENDUM

The additional data received in January, 1927, from the Chief of the Weather Bureau gives two complete 46-year cycles. As a result, predictions should be more accurate, although the probable inaccuracy of observations made nearly a century ago is so great that the gain can not be much. The predictions from the original data are given in the table under Data A, those from the more complete record under Data B. Sixteen predictions are unchanged among 24. Most of the changes are merely shifts across the dividing line between adjacent groups. In only one case, the latter half of 1927, is there any serious shift. For this epoch a prediction, which barely missed being normal, is shifted from dry to just outside of the normal group on the wet side.—*D. A., February 18, 1927.*

THE THUNDERSTORM AT CINCINNATI AND ITS RELATION TO ELECTRICAL POWER SERVICE

By W. C. DEVEREAUX

[U. S. Weather Bureau, Cincinnati, Ohio]

NOTE.—Ninetieth meridian time is used in this article, including the tables and charts. Seventy-fifth meridian time was adopted for Cincinnati by the Weather Bureau on January 1, 1927.

During the 11 years that the Abbe Meteorological Observatory has been maintained in Cincinnati, a most careful and detailed record of all the weather elements has been made. The thunderstorm, like the clouds, must be observed and described by trained observers—no instruments have been devised that will fully meet the requirements or take the place of scientific training. The average recorded number of days with thunderstorms at Cincinnati in the last 10 years shows an increase of 23 per cent as compared with the previous 10 years, due to improvement in the location of the place of observations, and in the methods of observation.

In this study of the individual thunderstorm it is necessary first to define the thunderstorm. Alexander, in his article on the distribution of thunderstorms, has quoted all the instructions to observers on the subject—the last one was issued in January, 1894—and stated that the instructions have been in force ever since. About the only instruction in force at present is that "a storm from which distinct thunder is heard will be considered a thunderstorm," while the instructions to cooperative observers add that "thunderstorms six hours apart may be considered as separate storms."

It is unusual for an individual thunderstorm to last more than two hours, while on the other hand several may occur within one hour. Frequently two or more separate thunderstorms may be visible at the same time. One summer evening distant and diffused lightning was observed in the north for about one hour after dark, then thunder was heard in the north and the separate lightning strokes became visible; other storms started in the west and southwest, until at one time four separate parts of a general storm were visible and thunder could be distinctly heard from each cloud mass—one in the northeast, one in the north, one in the northwest, and one in the west—all storms moving northeastward. Up to this time no rain had fallen at the station, but the next storm, which developed to the southwest, moved directly over the station, and the series of storms that evening were ususually severe. While these storm clouds were separated by a considerable distance, and the path of each was a few miles south of the preceding one, they acted together, and therefore the series should be considered a single thunderstorm. At other times we have observed two or three distinct storms in progress at the same time when there appeared to be very little, if any, physical connection between the clouds; these should be considered as separate storms.

Recently while traveling directly eastward by automobile from Cincinnati 150 miles, we passed along a line where a large number of thunderstorms developed. The sky continued mostly clear to the south, while in the rear, thunder would be first heard in a comparatively small cloud and the storm would pass rapidly north of us, moving to the northeast. Some were attended by rain. These storms developed eastward at the rate of 20 miles per hour, but the individual storms moved at an estimated rate of 40 miles per hour.

In this paper a thunderstorm will be defined as "a commotion in the atmosphere in which thunder is heard, each separate cloud mass attended by thunder to be considered an individual thunderstorm." The smallest thunderstorm observed at Cincinnati was on a clear, summer day. A small thin cloud formed in the southwest, and, as it moved directly toward the station, one dull peal of thunder was heard, after which the cloud dissipated as quickly as it had formed.

Our principal object in this paper is to show the variation in frequency of occurrence of the thunderstorm during each of the 24-hour periods at Cincinnati. Much has been written about the physical aspects of the thunderstorm, the annual and monthly variation, and the geographic distribution, but comparatively little about the daily variation. The principal exception is in Cox and Armington's "Climate of Chicago." Most of the authorities, as Ferrell, Davis, Ward, Humphreys, Alexander, and others state that thunderstorms are most frequent during the afternoon, but have little to say about the other hours of the day.

For study purposes, we entered on large sheets of cross-section paper all the data about each thunderstorm for the last 20 years, using one sheet for each month, except for the winter months, which were placed together on one sheet. On these charts were shown by symbols or figures the time and duration of each storm, the time of rainfall, the rate of heavy and excessive rains, the direction of movement, the type of the storm, and other information. As these charts were much too large to reproduce, two other and much smaller charts for 10 years have been prepared to show only the time and duration of thunderstorms. The third chart shows by vertical bars the total hours with thunderstorms for each hour during the year for a period of 20 years; the fourth one, the hourly variation by seasons, and for July, the month of greatest frequency.

In hourly frequency as well as i tensity the thunderstorm is naturally divided into four types or seasons, but the seasons differ somewhat from the seasons of the year. The summer type, which comprises about 8 per cent of all thunderstorms at Cincinnati, begins in May or sometimes late in April and usually ends about the last of August or early in September. During this season the stormiest hour is from 2 to 3 p. m., when the temperature is highest, and the least stormy is the hour ending at either 9 or 10 a. m., not at night or when the temperature is lowest, but during the hour of most rapid rise in temperature. In the month of greatest frequency—July—there have been 63 thunderstorms in 20 years for the hour ending at 3 p. m. and only 4 for the hour ending at 9 a. m. The fall thunderstorm, which occurs in September and sometimes in October, reaches a maximum about 3:30 p. m. and a minimum at 11 a. m. Both the summer and the fall thunderstorm appear to have a second maximum about 6 a. m. but this is probably due to a failure to record all thunderstorms between midnight and 6 a. m. The spring thunderstorm, during March and April, occurs most frequently during the afternoon,

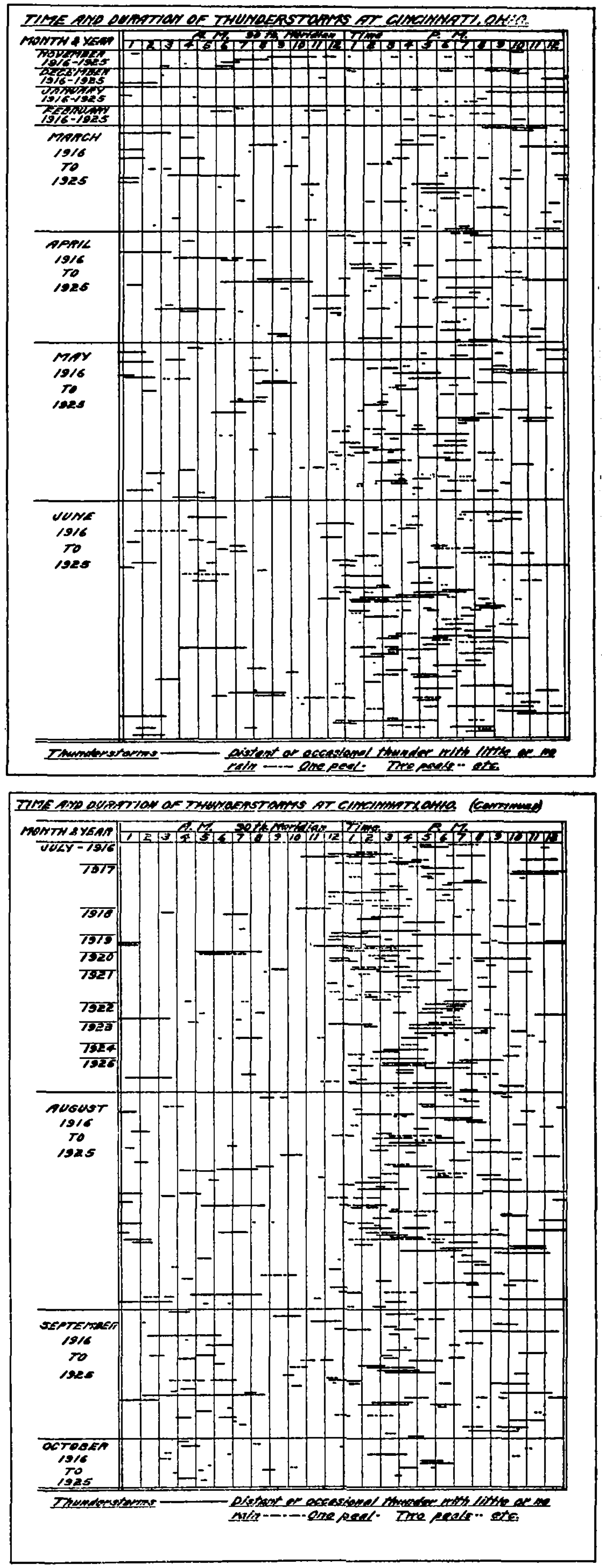

FIG. 1

reaching a maximum at 7 p. m., and occurs less frequently between 4 a. m. and 11 a. m., but the hourly variation is poorly defined. The winter thunderstorm from the last of October to the fore part of March shows but little variation during the 24 hours.

The largest recorded number of days with thunderstorms in any one month was 17, in July, 1917, with 27 separate storms. In June, 1919, there were thunderstorms on 15 days out of 30, and during the 15 days 30 separate storms occurred, which exceeded the number of storms in July, 1917.

Considering only the movement of the individual storm and not that of a series, it was found that about 90 per cent of all storms moved from a westerly to an easterly direction, and more than one-half of those moved from the southwest to the northeast. Only a few of the slow-moving heat thunderstorms moved either directly northward or southward, and it was frequently a question whether the storm was moving or developing toward the north or the south. The few thunderstorms, which have approached the city from the east or northeast, have nearly all been located in the "point of the wedge" formed by V-shaped isobars extending eastward from a low center over Missouri or the extreme lower Ohio Valley, with comparatively high pressure both north and south of the station. During 10 years of detailed record at the Abbe Meteorological Observatory no thunderstorms have been observed moving from the southeast to the northwest.

The tendency of all thunderstorms to move eastward is very pronounced, even under what appear to be adverse conditions.

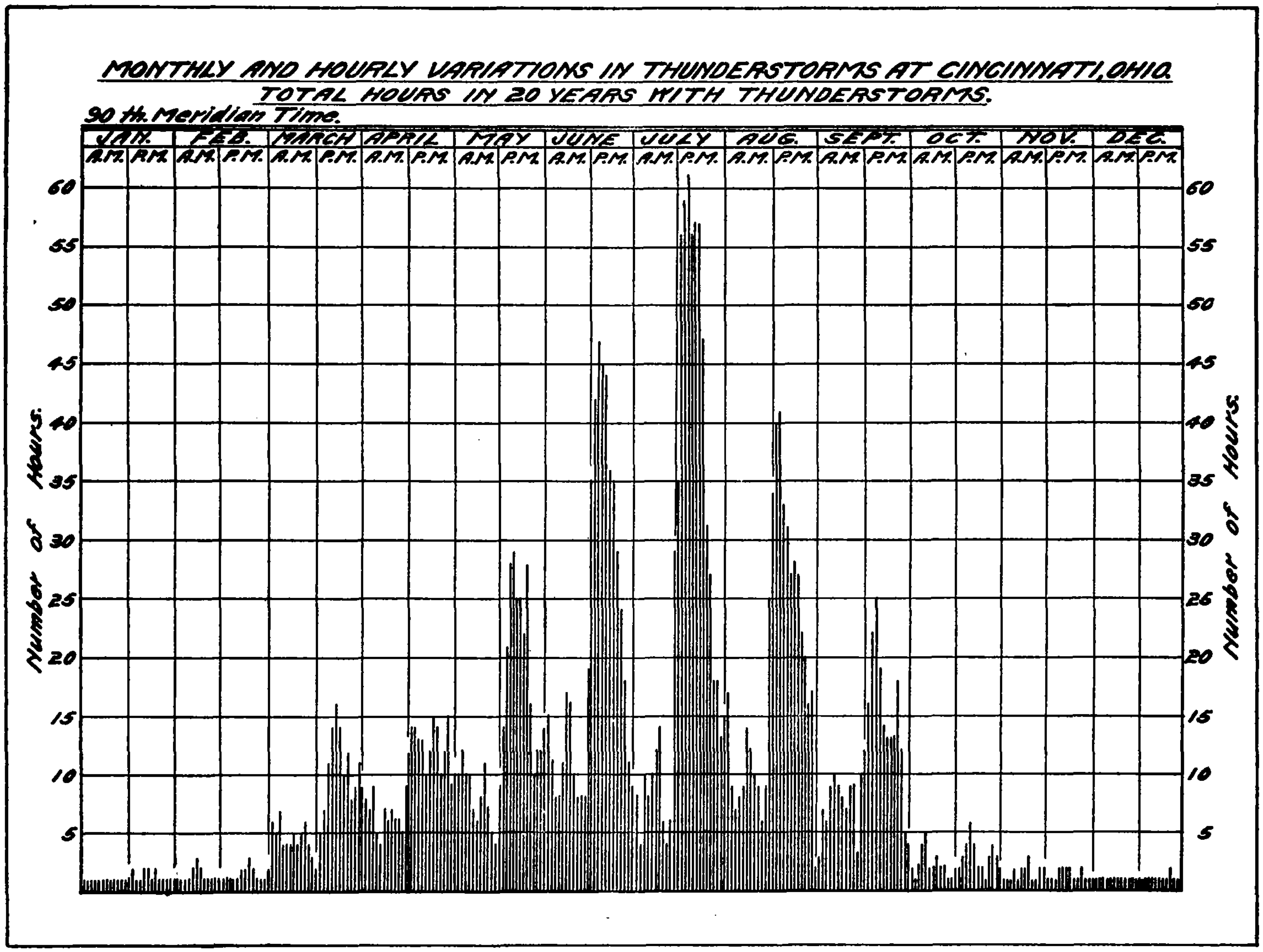

FIG. 2

Storms have been observed to move eastward against high strato-cumulus clouds moving from the east, and across fresh southerly winds. A few of the storms move with great rapidity, especially when associated with a rapidly moving LOW, but the surface wind is seldom over 30 miles per hour. In one storm thunder was first heard in the far southwest, and last heard in the far northeast 15 minutes later. If each of these peals was 10 miles from the station, the storm must have moved at the rate of 80 miles per hour. The highest surface wind in this storm was 25 miles per hour. The "heat" and "border" thunderstorm, and the thunderstorms in the "trough", are usually slow-moving storms, and frequently the most destructive.

Of the 340 thunderstorms that passed either north or south of the Abbe Observatory during the last 10 years, 200, or 60 per cent, of them passed north and only 40 per cent passed south of the station. South of the observatory is the central portion of the city with a great network of wires and many high buildings, but all located in the valley of the Ohio River; while north of the station is higher land with mostly open country except for a small thickly settled valley near-by, which, however, is sheltered by a ridge of hills on the west. Out of 213 storms charted for July, the month of greatest frequency, 52 passed over the station, 86 north of it, 40 south of it; of the remaining 35, a few passed either east of west of the station, but most of them were distant thunderstorms without apparent movement. In a recent paper on "Thunderstorms in the British Islands" the statement was made that, "In America the summer storms (thunderstorms) occur very largely along the main valleys," and similar statements have been made by other meteorologists, but the conditions do not appear to be true for the middle Ohio Valley.

The occurrence of thunderstorms and the variation in the time of occurrence depend on the meteorological factors and the time elements. The two most important weather elements are the distribution of pressure and the temperature of the air—and the two equally important time elements—the time of the year and the hour of the day. Each of these may be divided into three phases of favorableness to thunderstorm occurrence—the maximum, the intermediate, and the minimum phase. The maximum phase of pressure distribution is a LOW northwest of the station and higher pressure to the south, the intermediate is when the weather map is "flat," and the minimum is when the pressure is high north of or over the station. The maximum phase of temperature is temperature considerably above the normal for the hour, the intermediate is normal temperature with high humidity, and the minimum is temperature low for the hour. In the time elements the maximum phases are May to September and between the hours of 11 a. m. and 8 p. m., the intermediates are the early spring and late fall months and the hours from 8 p. m. to 8 a. m., and the minima are the months from November to February and the hours between 8 a. m. and 11 a. m. throughout the year. When the four maximum phases are in conjunction the thunderstorm develops, when some of the intermediate phases occur with the maximum phases the thunderstorm frequently develops, but when two or more minimum phases are in the series the storm does not develop. Other weather elements are factors of some importance in producing thunderstorms, but these, as well as temperature, are connected with and result from the pressure distribution. When the thunderstorm develops, the LOW is nearly always present to the west, northwest, or north of the station, but is often poorly defined and apparently shallow. These rules, if they may be so named, apply best to the last half of the day during the summer months. The occasional winter thunderstorms and those occurring after midnight obey few if any evident rules.

Doctor Humphreys in the MONTHLY WEATHER REVIEW for June, 1914, presents five types of weather maps attended by thunderstorms. These types and thunderstorms which attend them are defined briefly as: *a*, Regions of high temperature and widely extended and nearly uniform pressure, "heat" thunderstorms; *b*, the southeast quadrant of a LOW, "cyclonic" thunderstorms; *c*, the barometric valley between the branches of a V-shaped cyclonic isobar, "tornadic" thunderstorm; *d*, the region covered by a low-pressure trough between adjacent high-pressure areas, "trough" thunderstorms; and *e*, the boundary between warm and cold waves, "border" thunderstorms. The 1,500 thunderstorms at Cincinnati in the last 20 years have nearly all been in connection with four of these types of weather maps in roughly the following proportions: Forty per cent each of "heat" and "cyclonic" thunderstorms and 10 per cent each of "trough" and "border" thunderstorms. The "tornadic" thunderstorm is practically unknown at Cincinnati. Many similar types of weather maps were found which were not attended by thunderstorms, at least not in the vicinity of Cincinnati, but in nearly every such case the date was between October 1 and March 31, or the hour was between 8 a. m. and 11 a. m. or, for some reason, the temperature did not rise much above the normal for the hour.

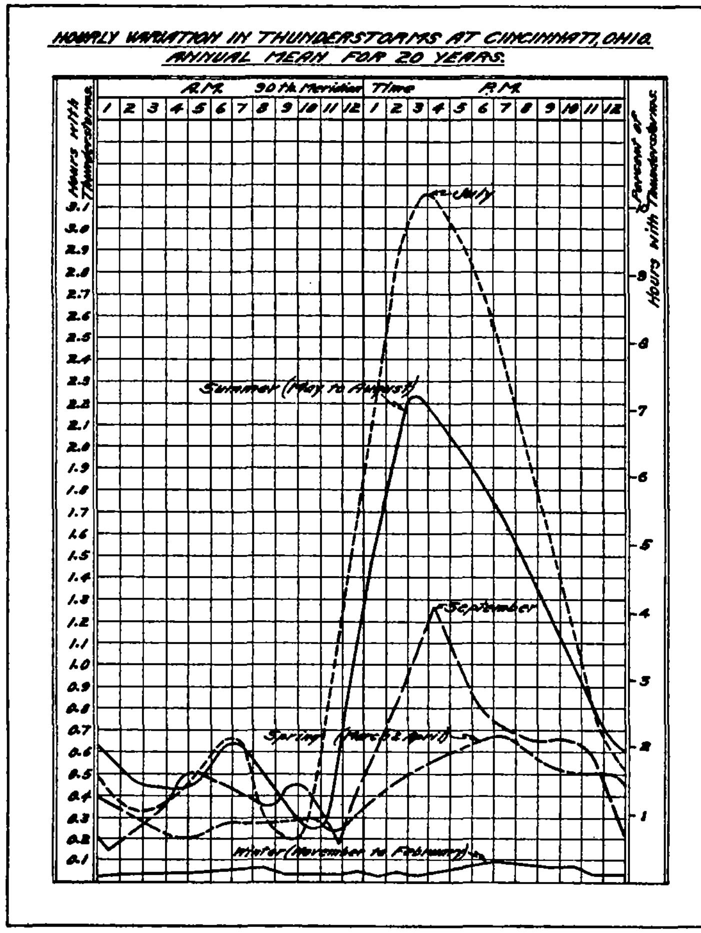

FIG. 3

THE THUNDERSTORM IN RELATION TO ELECTRICAL SERVICE

The Union Gas & Electric Co., of the Columbia system, Cincinnati district, has prepared a large amount of data for use in this article, on the effect of storms on a great modern electric system. Unfortunately space will not permit the reproduction of the large number of charts and tables submitted, but all of the material has been carefully studied and the results, with other thunderstorm data, summarized in Tables Nos. 1 to 4.

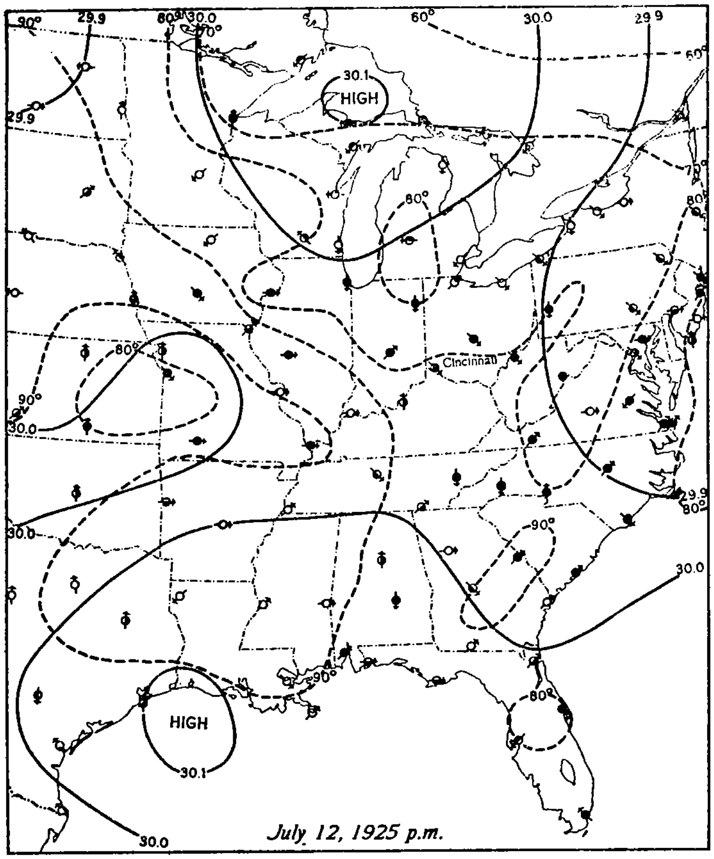

FIG. 4.—Pressure and temperature distribution which accompanied a thunderstorm of the "heat" type

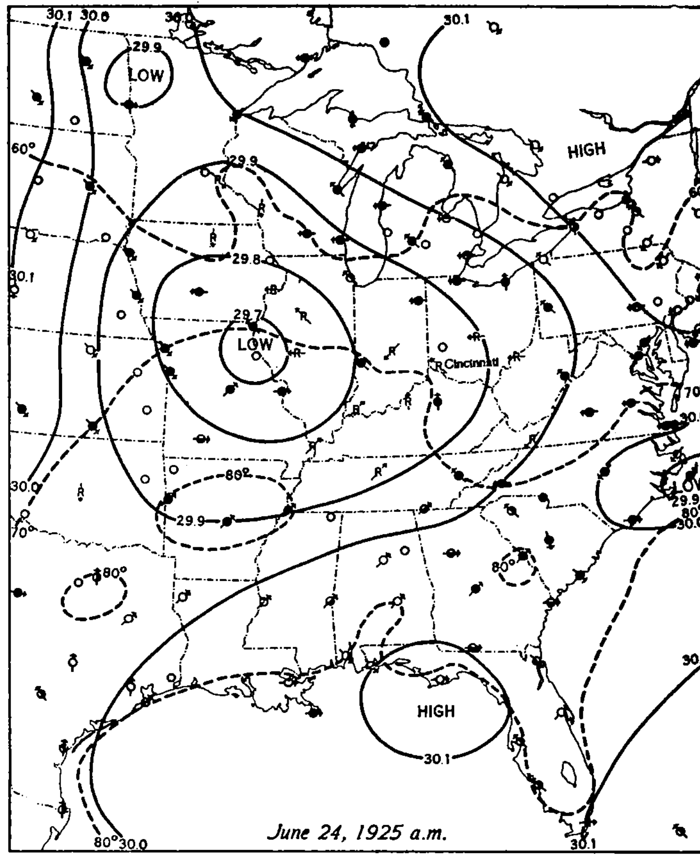

FIG. 5.—Pressure and temperature distribution which accompanied a thunderstorm of the "cyclonic" type

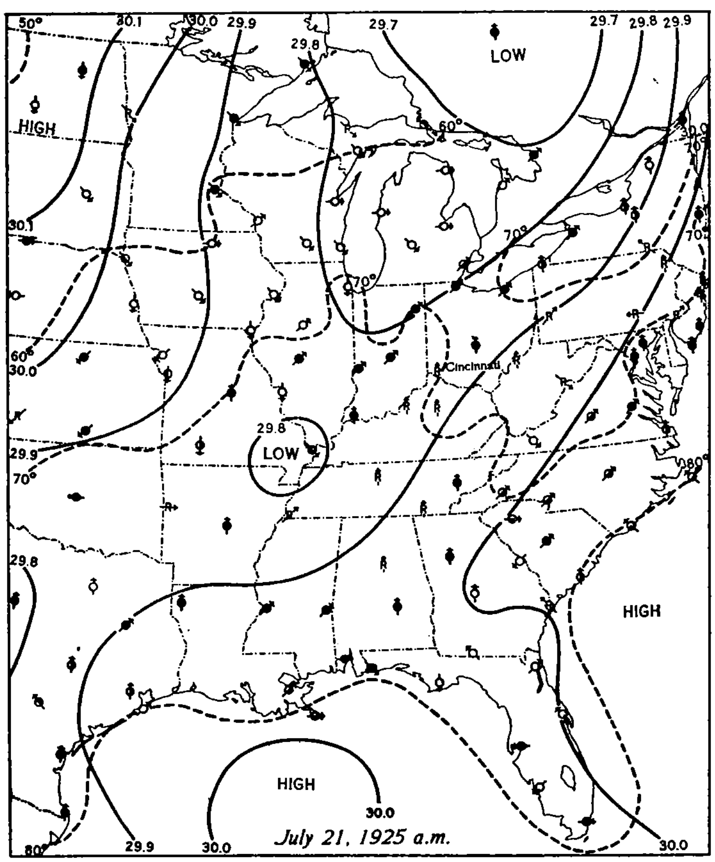

FIG. 6.—Pressure and temperature distribution which accompanied a thunderstorm of the "trough" type

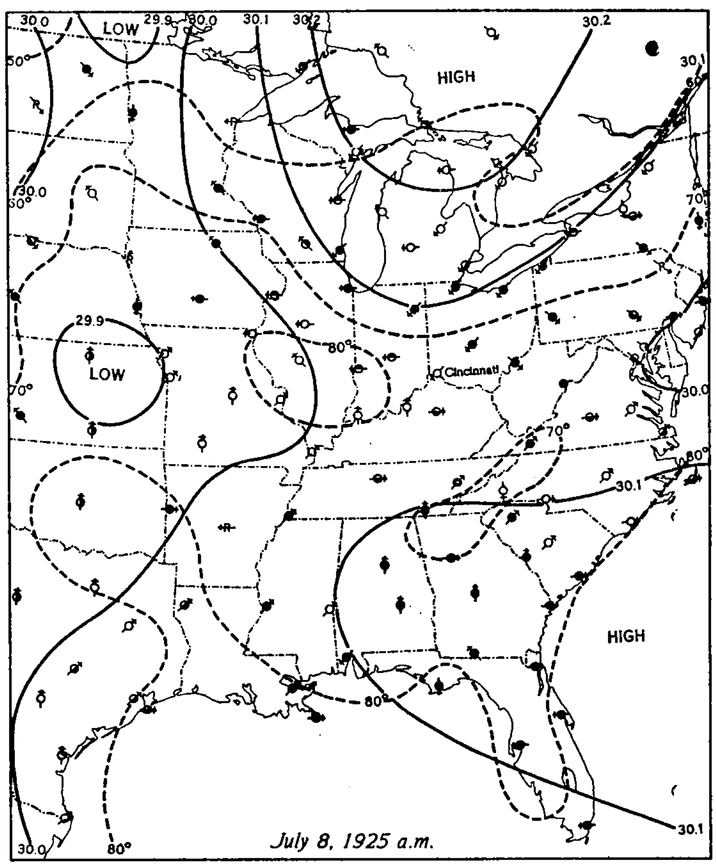

FIG. 7.—Pressure and temperature distribution which accompanied a thunderstorm of the "border" type

The remarkable features of the tabulations are the great growth of the electric service in the Cincinnati district during the last 10 years, and more especially during the last five years; the great increase in the amount of damage by thunderstorms to the electric system. The wind when not attended by a thunderstorm occasionally causes considerable damage, but in a region where the maximum wind velocity seldom exceeds 40 miles per hour, and exceeded 50 miles only two times in 10 years, the damage caused by the wind alone is not great. The sleet, snow, and other similar elements are minor agents of destruction to the electric system.

A "storm log" was prepared by the department of operation of the Union Gas & Electric Co. for the years 1921 to 1926, inclusive. It was difficult to obtain the information for the years 1921 to 1923, and as there were comparatively few overhead circuits in operation previous to 1921, the report was not extended back to 1917. The report for 1921 shows that the amount of trouble was comparatively small and the number of outages listed does not give a true idea of the number of storms. For that reason the report for 1921, though included in Tables Nos. 1 and 2, showing the growth of the system, is not included in Tables Nos. 3 and 4, showing the effect of the storms.

TABLE 1.—*Growth of the Columbia electric system in the Cincinnati district*

NUMBER AND MILEAGE OF OVERHEAD CIRCUITS IN SERVICE AND NUMBER OF CONSUMERS 1921 TO 1926

Year	4,325 volts	13,200 volts		33,000 volts		66,000 volts		Total except 4,325 volts		Commercial consumer	Total area (square miles)
		Number	Miles	Number	Miles	Number	Miles	Number	Miles		
1921	(1)	7	26	6	87	0	0	13	113	64,429	236
1922	(1)	7	32	7	94	0	0	14	126	77,292	
1923	(1)	8	37	9	132	3	48	20	218	93,466	
1924	(1)	14	54	9	147	4	71	27	271	107,425	
1925	(1)	16	58	9	151	14	171	39	381	119,363	
1926	(1)	21	71	11	147	14	171	46	389	127,439	270

[1] No data available.

TABLE 2.—*Damage from storms, by years, to Columbia system, Cincinnati district*

Year	Days with thunder storms	Destructive storms		Total time of outages	Number of circuits out			Commercial trouble calls	
		All storms	Thunder storms		All storms	Thunder storms	Maximum in 1 thunder storm	Average daily for the year	Maximum for 1 thunder storm
				h. m.					
1921	77	13	13	29 49	43	42	12	46	160
1922	53	31	15	48 32	98	80	11	54	185
1923	42	24	19	65 33	124	98	11	81	290
1924	50	43	15	167 3	537	327	55	91	445
1925	58	46	34	141 24	522	453	53	110	715
1926	57	46	30	304 42	754	645	105	116	1,060

TABLE 3.—*Storms and circuits out by months, Columbia system, Cincinnati district*

Month	1922—Destructive storms			1923—Destructive storms			1924—Destructive storms			1925—Destructive storms			1926—Destructive storms		
	All classes	Thunderstorms	Outages	All classes	Thunderstorms	Outages	All classes	Thunderstorms	Outages	All classes	Thunderstorms	Outages	All classes	Thunderstorms	Outages
January	0	0	0	2	0	5	1	0	4	3	0	12	4	0	15
February	1	0	3	0	0	0	1	0	15	3	0	35	3	0	32
March	4	2	17	3	1	22	5	1	100	5	4	17	0	0	0
April	4	4	13	1	0	1	5	2	44	6	6	26	3	1	15
May	4	4	10	2	2	7	5	4	34	4	3	27	5	5	195
June	1	1	4	2	2	12	8	8	162	6	5	59	7	7	147
July	4	4	7	8	8	40	4	4	39	9	9	254	8	8	227
August	10	8	38	6	6	37	6	5	58	5	5	41	6	4	136
September	3	2	6	0	0	0	2	1	16	2	2	32	7	5	47
October	0	0	0	0	0	0	1	0	64	1	0	1	3	0	45
November	0	0	0	0	0	0	2	0	8	2	0	18	----	----	----
December	0	0	0	0	0	0	3	0	21	0	0	0	----	----	----

TABLE 4.—*Hourly distribution of thunderstorms and hourly distribution of damage from thunderstorms to Columbia electric system in circuits out (outages) for 1922 to 1926, inclusive*

	Ninetieth meridian time																							
	A. M.												P. M.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Number of hours with first thunder	9	6	7	7	7	9	11	8	4	4	6	21	25	24	28	30	20	26	22	13	19	10	10	8
Hours with thunderstorms	17	20	19	13	12	14	17	18	10	7	8	24	34	42	53	58	57	56	53	43	35	28	28	17
Hours with first outages	7	4	4	1	2	1	0	4	0	2	2	12	18	13	10	13	15	16	7	4	6	4	2	6
Total hours with outages	13	13	11	10	10	10	6	7	4	4	4	15	27	37	41	45	47	53	46	42	33	23	12	7
Total outages	67	73	39	16	16	9	2	19	6	16	11	163	223	156	117	75	92	107	112	84	49	40	37	74
Per cent of storms destructive	78	67	56	14	28	11	0	50	0	50	33	57	72	54	36	43	75	62	32	31	32	40	20	75

The storm log shows for each storm causing trouble the date of the storm, time circuits were out, locality affected, direction of movement, number of outages, weather conditions, and effect on the system. Another department prepared charts showing the number of commercial trouble calls each day for 10 years, showing not only the average number of daily trouble calls but also the additional number of calls for each storm. Combining these two records with the record of each thunderstorm by the Weather Bureau we obtain a complete history of each thunderstorm and the effects on the electric system. A summary of the results obtained is shown in the tables. In using the tables, especially in comparing the number of outages and trouble calls in 1921 or 1922 with later years, as shown in Tables Nos. 2 and 3, allowance must be made for the growth of the system, as shown in Table No. 1, under number and miles of overhead circuits and number of commercial consumers. During the same period the area covered by the overhead circuits has increased from 236 square miles in 1921 to 270 square miles in 1926.

In addition to the information contained in the tables, the storm log shows interesting details of the damage from the thunderstorm under the "effect on the Columbia system." In 1921 and 1922 the damage consisted entirely in putting out of commission the 4,325 volts, 13.2 kilovolts, and 33-kilovolt lines. The 66-kilovolt lines were constructed in 1923, but were not in operation until the end of 1925. In 1922 and 1923 in addition to the various circuits being out, trouble was also experienced in flashing of insulators, causing bad potheads, hot crosses, and burning out rotary converters.

"Surges" became a prominent source of trouble from the thunderstorm late in 1924, and continued to cause much trouble the two following years. Surges are the dropping of the load on a high-tension line, such as 33 kilovolts, to say, 15 kilovolts, a rise above 33 kilovolts, and then a drop again. This kicks out the circuit. During the year 1925 surges during 10 of the 34 destructive thunderstorms caused 184 outages and probably several more.

Storms during these years apparently caused considerable trouble with arc circuit and direct-current machines. In the storm log no mention is made of machines being out until April 24, 1926, when the following appears: "Six outages on 66-kilovolt circuits and 5 machines out due to surges." During the remainder of 1926, there were 96 machines out in 17 thunderstorms. This was the first full year of service from the Columbia station, located on the Ohio River 20 miles below Cincinnati, with 171 miles of high-voltage lines transmitting current. Other causes of trouble mentioned most frequently during the last year were: Poles on fire, hot crosses, arc circuits out, and lightning arresters hit.

The area of observation of thunderstorms at the Abbe Meteorological Observatory is practically the same as the area covered by the network of the Columbia system at Cincinnati. The frequency and intensity of the storms as observed have been compared with the damage to the electric system. The electric-power company is only one of the industries affected by the thunderstorm, and similar industries suffer corresponding losses throughout the region of thunderstorms.

CAN THUNDERSTORMS BE CLASSIFIED?

ALFRED J. HENRY

The Editor is moved to these remarks by the classification of thunderstorms given by Mr. Devereaux on p. 115.

Scientists are perhaps never so well satisfied with their efforts as when they have succeeded in classifying some particular phenomenon that hitherto had escaped the hands of the classifier. Classification is common to practically all writers on scientific subjects. First, they observe and then they sort into groups or classes those objects which have one or more features in common, and by this method they arrive at "genera" and then "species," and so on. In the biological sciences such procedure is logical and helpful since the difference between any two classes of objects is significant.

When, however, one attempts to class thunderstorms he must sooner or later discover that about the only thing they have in common is their dependence as to origin on atmospheric instability, however that is brought about.

It has been recognized for many years that one of the two so-called types of thunderstorms, "heat" and "cyclonic" shades imperceptibly into the other and that it is not practicable to distinguish between them.

This was recognized by Mohn and Hildebrandsson, who were probably the first writers to class thunderstorms into two main groups as above indicated. These authors expressly say: "However, it is in Sweden impossible to find a well-defined boundary between these two classes of thunderstorms." [1]

Hann and Süring in the former's well-known Lehrbuch, follow Mohn and Hildebrandsson and add a third group, viz, those which originate along the borders between warm and cold areas. This class was not named.

It is but natural that further study of thunderstorm phenomena should disclose a greater variety of conditions of origin than has hitherto been recognized, especially if, as Humphreys has done, the form of the isobars at or very shortly after the occurrence of the thunderstorm be made the criterion of classification. Humphreys, as stated by Devereaux, describes five classes, viz, heat, cyclonic, tornadic, trough, and border. The two first named and the last named have already appeared in the literature.

Any classification to be useful should be adopted by the majority of organized weather services; pending such adoption it would seem to be preferable not to stress the grouping by classes, remembering that to the man on the street a thunderstorm is a thunderstorm and nothing more; moreover, there do not seem to be any well-recognized differences between thunderstorms that could be used as criteria for classification.

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[1] Les Orages dans la Peninsule Scandinave. Upsala, 1888.